Unmasking the Mysteries of High-Mass X-Ray Binaries (HMXBs): The Role of LLNL's Electron Beam Ion Trap (EBIT)

Carey Baxter[1], Natalie Hell[2], Greg Brown[3]
[1]California State University, Long Beach, CA [2]Remeis-Observatory/ECAP, University of Erlangen-Nuremberg, Germany
[3]Lawrence Livermore National Laboratory, Livermore, CA

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GOAL 1

- To analyze X-ray line spectra of excited, highly charged silicon (Si) produced by EBIT.

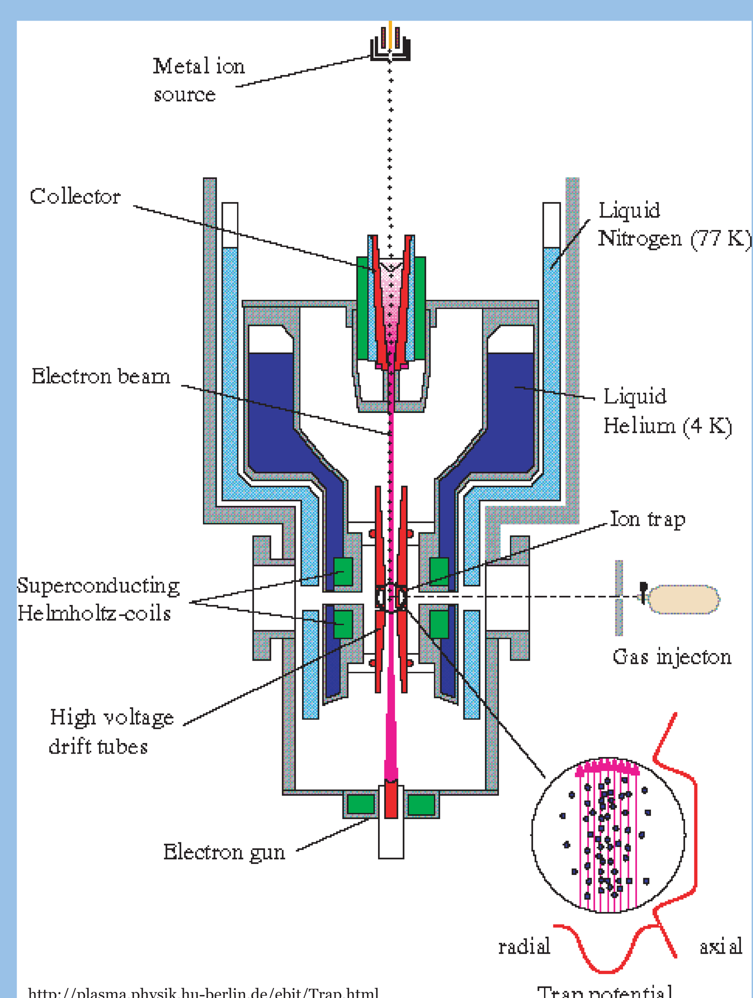
PURPOSE

- To use data as a point of reference for similar spectra measured by satellites *Chandra* and *XMM-Newton*.
- To calculate Doppler shift of X-ray lines and, in turn, ion velocity around HMXBs.

BACKGROUND 2

EBIT

- EBIT uses a narrow electron (~60μm) beam to excite and trap ions.
- X-ray emission from the excited ions is then diffracted using crystal spectrometers and analyzed.



http://plasma.physik.hu-berlin.de/ebit/Trap.html

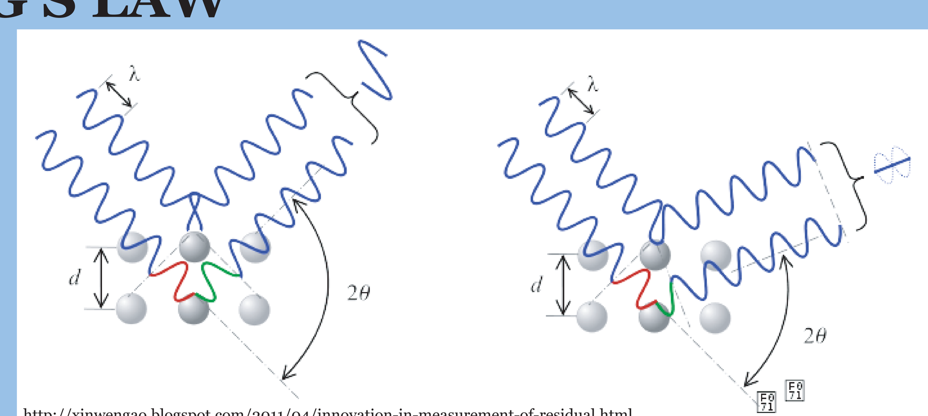
WHY EBIT IS IMPORTANT

- High precision, high accuracy
- Provides spectral data that can't be calculated
- Helps astronomers to better understand wind movement around HMXB accretion disks

CRYSTAL SPECTROMETERS DIFFRACT X-RAYS ACCORDING TO BRAGG'S LAW

$$N\lambda = 2d\sin\theta$$

N – integer
λ – wavelength of incident wave
d – space between lines or atoms in target material
θ – angle between incident ray and scattering planes


http://xinwengao.blogspot.com/2011/04/innovation-in-measurement-of-residual.html

Bragg diffraction occurs when electromagnetic waves (like X-rays) encounter obstacles (like atoms in a crystal) whose spacing is comparable to the wavelength.

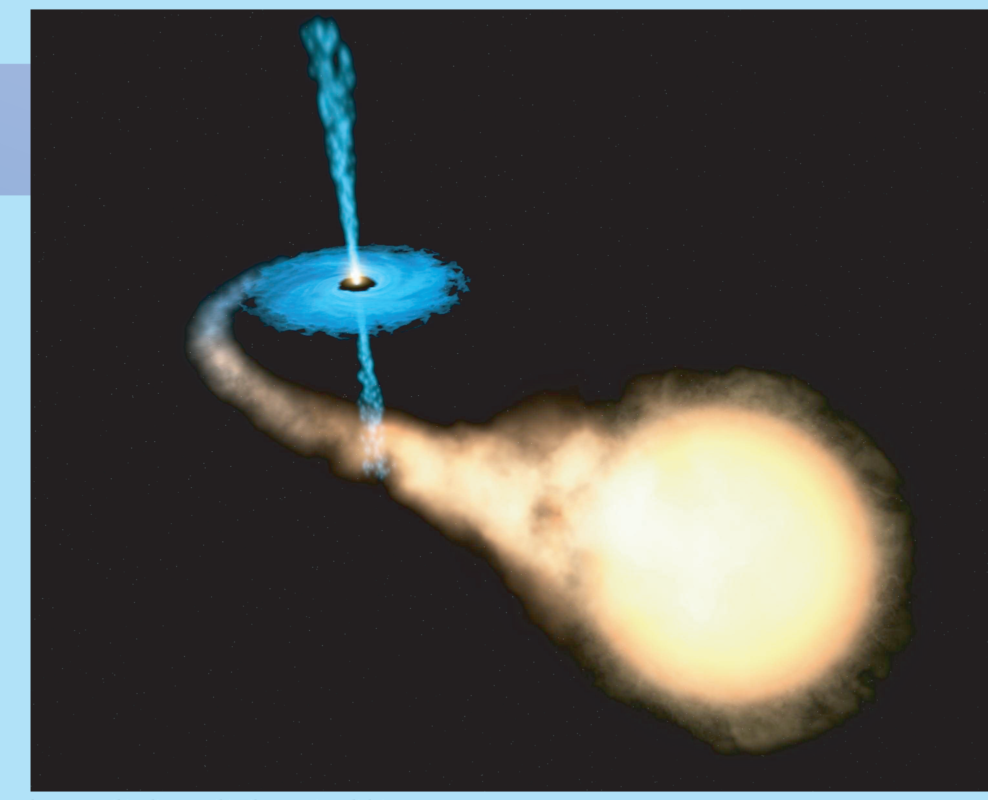

http://www.nasa.gov/vision/universe/starsgalaxies/chandra7years.html

Satellites *Chandra* (left) and *XMM-Newton*.


http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=18015

APPLICATION 3

- Monoenergetic electron beam allows for isolation of single charge state.
- Can probe different excitation mechanisms.
- Accuracy of better than ~5mÅ is achievable.
- Can calculate Doppler shifts of Si spectra and learn about wind around HMXBs' accretion disks.

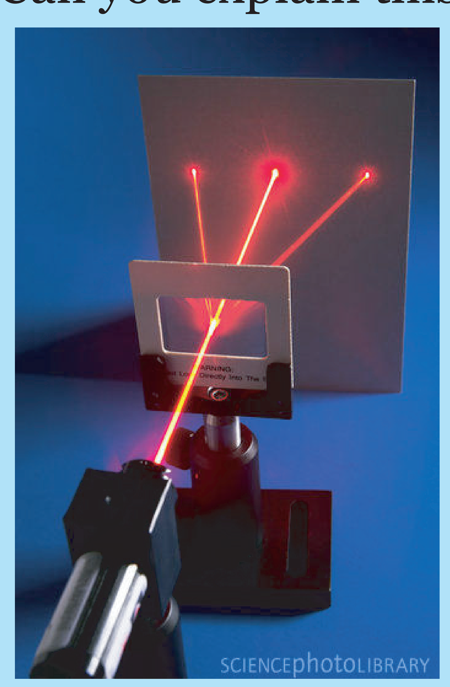

http://en.wikipedia.org/wiki/File:Accretion_disk.jpg

Artist's rendering of a HMXB: A compact object (left, neutron star or black hole) and its companion, or donor, star.

IN THE CLASSROOM 4

The Nature of Light: Diffraction and Interference

Can you explain this?


http://www.sciencephoto.com/media/92635/view

- *Diffraction* – the bending of waves around an object
- *Interference* – a phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude

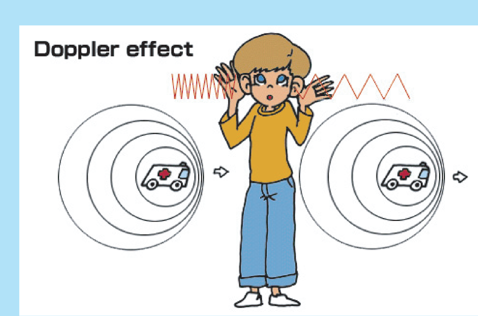
- Challenge: Use these concepts to:
  - Find track spacing of CD and DVD
  - Find diameter of lycopodium spore

Wave Behavior: The Doppler Shift

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

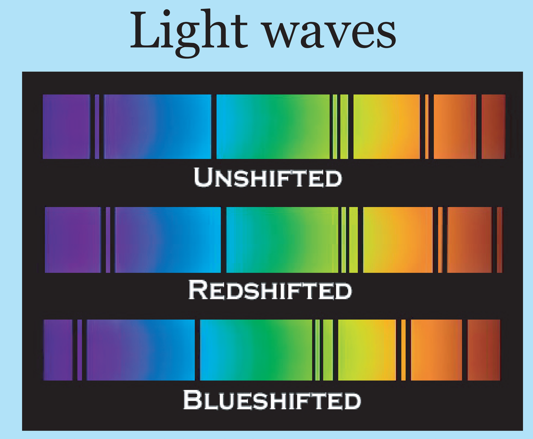
$\Delta\lambda$ = wavelength shift
λ_0 = wavelength of source not moving
v = velocity of source
c = speed of light

Sound waves



http://www.redorbit.com/education/reference_library/space_1/universe/2574658/doppler_effect/

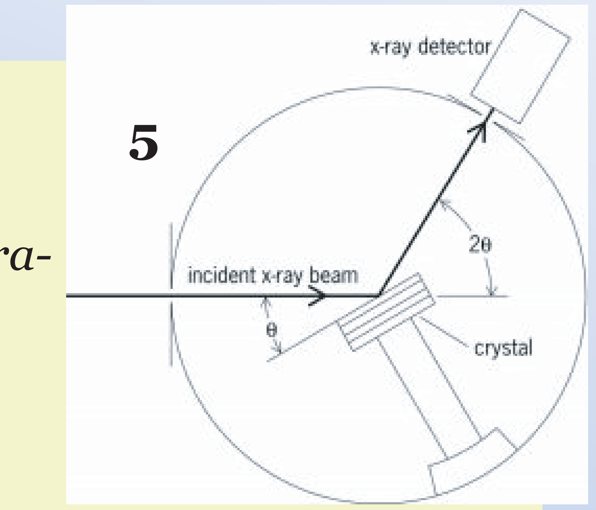
Light waves



http://www.astro.virginia.edu/class/oconnell/astr121/guide10-104.html

PROCEDURE 5

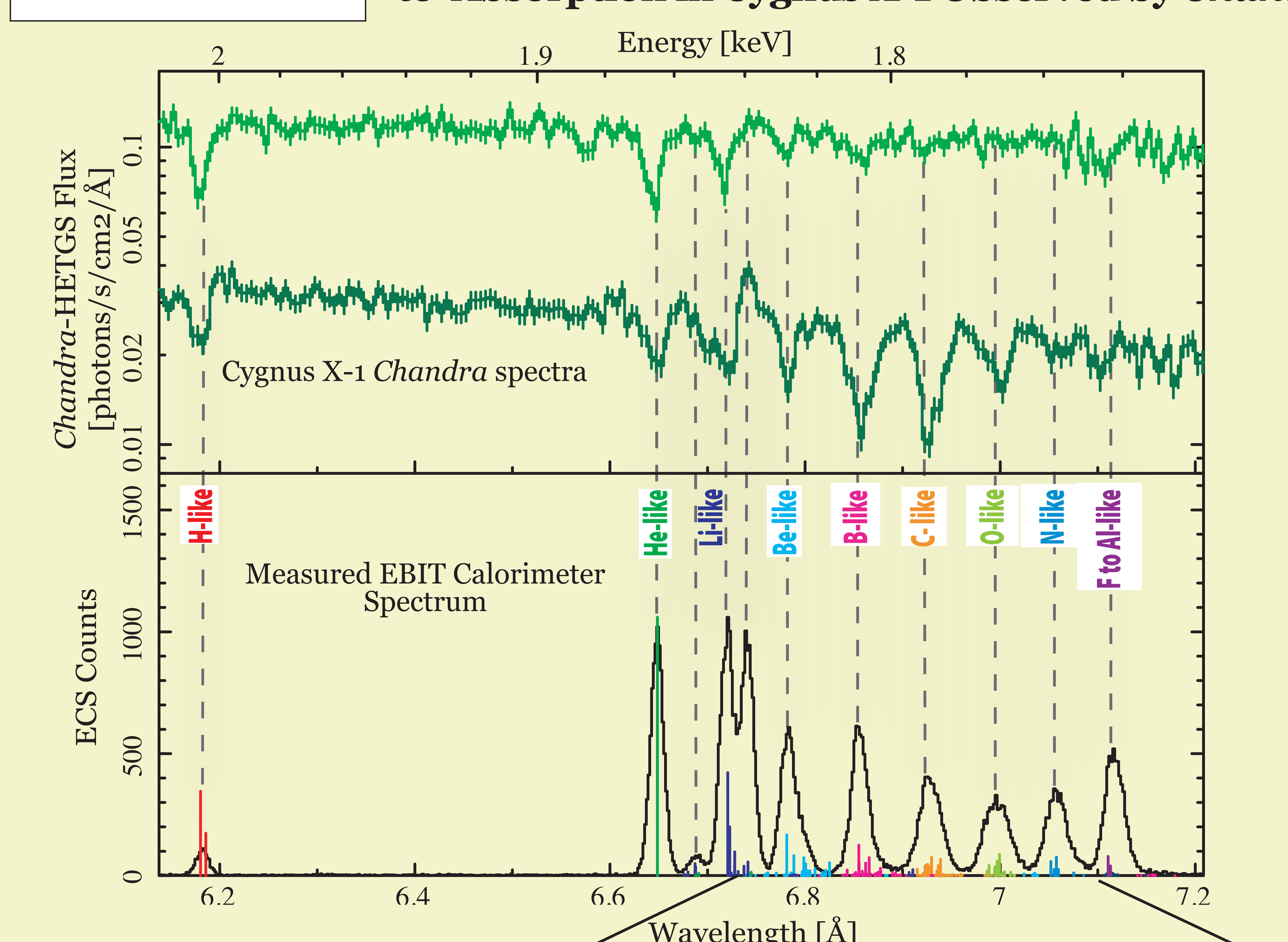
1. Injected Si (in the form of *decamethyltetrasiloxane*) into EBIT.
2. Used EBIT's monoenergetic electron beam to produce and excite highly charged Si ions Si^{5+} to Si^{12+}.
3. The strongest 2 to 1 transitions in each charge state were measured using a crystal spectrometer and an X-ray calorimeter.
4. The wavelength scale was calibrated using well-known wavelengths from hydrogenic and helium-like ions.



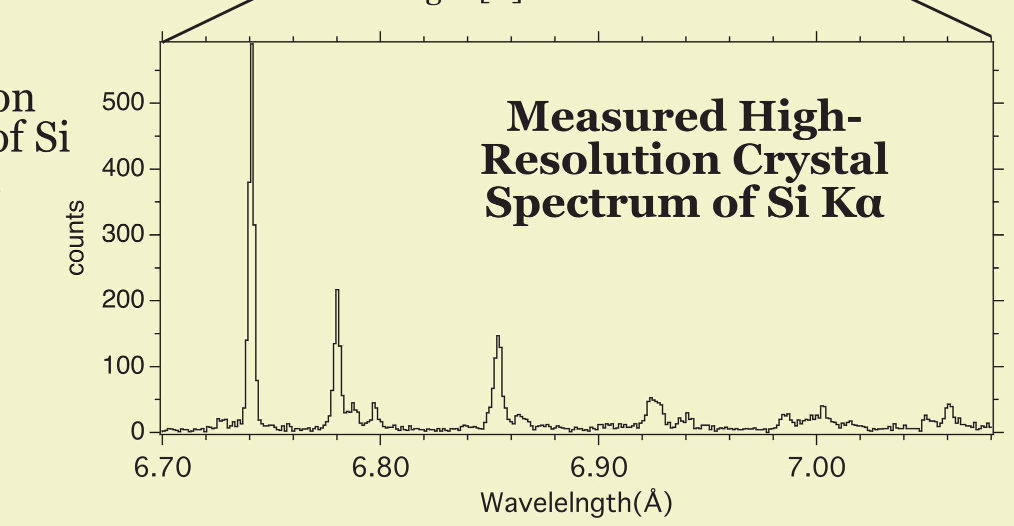
http://encyclopedia2.thefreedictionary.com/x-ray+diffraction

RESULTS 6

Si Kα Spectra: EBIT-Generated Emission compared to Absorption in Cygnus X-1 Observed by *Chandra*



The high-resolution crystal spectrum of Si resolves blends in Calorimeter and *Chandra* spectra.



- Absorption lines of highly charged Si ions have been observed in the spectra of Cygnus X-1.
- In order to determine if the measured absorption lines are Doppler-shifted, rest energy line centers are needed.
- The lower panel shows the Kα transitions of several charge states of Si measured with the EBIT Calorimeter. Spectrometer (ECS) at LLNL while the ions are at rest.
- Overlaid are the color-coded theoretical calculations of these lines.
- Some Si ions are Doppler shifted. Ion velocities of ~200 km/s were determined.

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